A STUDY OF WISCONSIN TILL PEBBLES IN OHIO: RELATIONSHIPS BETWEEN ABUNDANCE AND DISTANCE FROM THE SOURCE

A Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Bachelor of Science

by

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ABSTRACT

Late Wisconsin tills in Midwestern U.S.A. contain varying abundances of igneous and metamorphic rocks derived from the Precambrian Shield of North America. The relative abundance of these clasts is determined by the distance from their source province. The Wabash and Powell-Union City Moraines of Ohio and Indiana indicate that the abundance of igneous and metamorphic clasts in the +5 mesh fractions of till decreases southward and with distance from their source. Samples from the Cuba Moraine of Ohio and from the Port Huron, Galt, Orangeville, Paris, and Dummer Moraines of Ontario, Canada show different rates of change of the abundance of igneous and metamorphic clasts compared to the Wabash and Powell-Union City Moraines. Complications due to additions of previously deposited tills, variable bedrock lithology and different rates of melting are major causes of this difference. Understanding of these factors combined with glacial mechanics may lead to an empirical model that relates the abundance of clasts to the distance of transport.

ACKNOWLEDGMENTS

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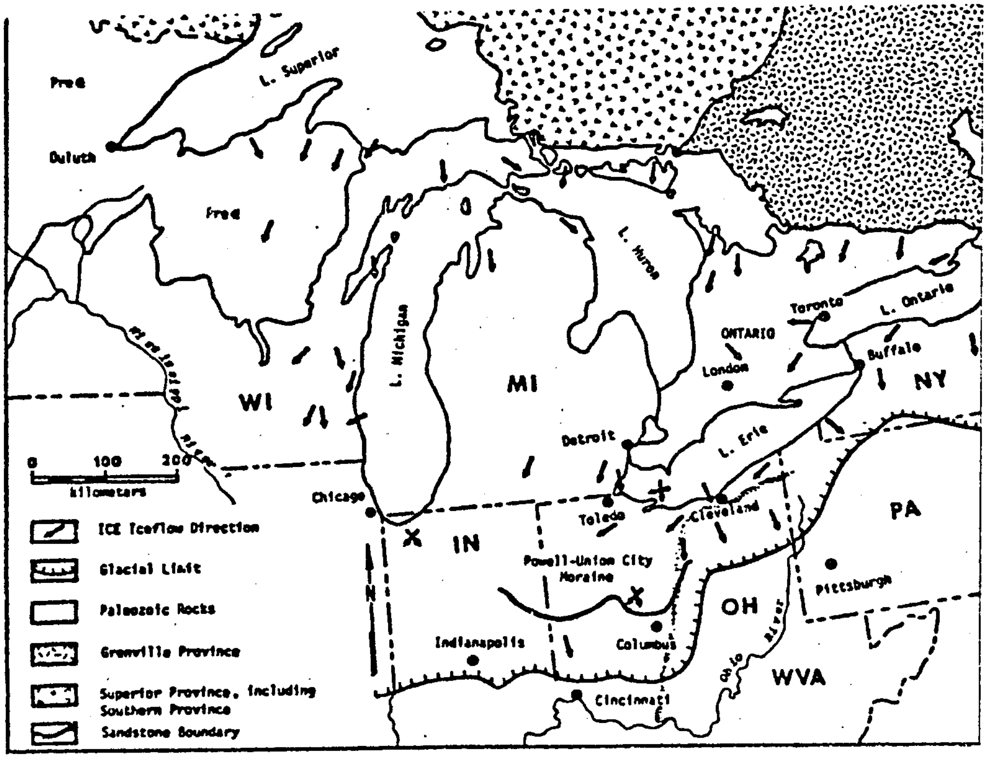
INTRODUCTION

Studies of the erosional and depositional features of Pleistocene continental glaciation aid in the understanding of ice-flow mechanics. The individual constituents of glacial till relate to the particular provenance over which the ice has passed. Knowledge of the provenance of distinctive components of till permits interpretations in terms of ice-flow patterns and sheds light on questions regarding the extent of reworking of glacial deposits by subsequent advances of the ice sheet (Taylor and Faure, 1981). Previous studies relating the till to ice-flow and provenance by Horberg and Anderson (1957), MacClintock (1933), and Holmes (1952) have determined source and direction of the Wisconsin glacial pattern. A generalized interpretation of the ice-flow is included on the Glacial Map of the United States East of the Rocky Mountains (Geol. Soc. of America, 1959)(Figures 1 and 2).

Moraines have been a major focus in the glacial studies due to their concentrated abundance of transported and deposited materials. The composition of a moraine is dependent upon the source of the ice and the composition of its floor (Anderson, 1957). Percentages of original bedrock materials in a till can be estimated from a knowledge of the distribution of the rock types that underlie the bedrock surface from which the till was derived (Harrison, 1960). Reversing this idea, a knowledge of the

Figure 1: Section of the Glacial Map of the United States East of the Rocky Mountains (Geol. Soc. of America, 1959)

Figure 2: Regional map of midwestern U.S.A. and Ontario. Adapted by Taylor and Faure (1981) from the Geological Map of North America (U.S. Geol. Survey, 1965) with generalized ice flow directions from the Glacial Map of the United States East of the Rocky Mountains, (Geol. Soc. of America, 1959).



abundance of different lithologic varieties of clasts, along with an understanding of transportation capabilities of glacial ice, should allow one to determine their provenance and hence the distance of transport.

Previous studies of transportation and sediment suspension of glacial ice have derived a variety of results. A basic premise is that all lithologies exhibit a decrease in number of [till] pebbles with a distance from source (Anderson, 1957 and Dreimanis and Vagners, 1972). However, discrepencies exist in the observed rates of decrease. Holmes (1952), in his study in west-central New York stated that more than 90 percent of the drift was carried by the Ontario glacier not more than 50 miles from its place of derivation. Harrison (1960), in his study of Wisconsin till in Indiana, found that the percentages of bedrock types in the typical till indicate that about 90 percent of it (by weight or volume) consist of bedrock materials derived from outcrops more than 100 miles upstream from the locality of till deposition. Moreover, Harrison stated that the materials may be picked up and transported by glacial ice for distances in excess of 1200 miles. A complication in computing the transport abilities of the ice is the problem of re-advances of glaciers over previously deposited till. This reconstitution of the components would create a new till of varying composition. Weathering of the older drift prior to a second advance causes relatively minor compositional changes (Gravenor, 1954) and, except for the superficial zone leached of carbonates, the total volume of drift affected by weathering is negligible (Harrison, 1960).

The analysis of till pebbles has been previously used as a method to examine glacial deposits. Krumbein (1933) used till pebbles to study the textural and lithologic variations in glacial tills from the Valparaiso Moraine of Illinois, and pebble and sand lithology of the major Wisconsin glacial lobes of the Central Lowland. Horberg (1953) studied the drift underlying the Wisconsin glaciation deposits of Illinois. MacClintock (1933) used detailed pebble analysis in correlation of the pre-Illinioian drifts of Illinois. Holmes (1952) used "pebble counts" in studies of drift dispersion in west-central New York. The majority of the studies involving till pebbles dealt in dividing the till into individual components on the basis of lithology and age to determine the source provenance and ice-flow direction.

The late Wisconsin tills of Ohio and Indiana contain crystalline clasts derived from the Grenville and Superior structural Provinces of Canada. The sources of the sedimentary clasts in the till deposits are limestones, dolomites, sandstones and shales of Paleozoic age that form the bedrock of this region.

Assuming that the crystalline pebbles of the Ohio and Indiana tills are derived from the Grenville and Superior Provinces, the abundance of these Canadian clasts should decrease proportional to distance southward. In order to test the validity of this statement, I have analyzed till samples from three major moraines lying parallel to one-another, each perpendicular to the advancing ice-flow. Aside from local variations, each moraine should exhibit a constant abundance level of crystalline clasts along its length.

REGIONAL SETTING

The north-western region of Ohio was subjected to glaciation during several periods of the Pleistocene epoch, creating a distinct geomorphologic difference from that of the unglaciated southeastern region. Unlike southeast Ohio, which belongs to the Appalachian foothills, the central and northwest area is relatively flat, aside from structures created by glacial deposition (Figure 3). Among the many glacial moraines in the region, I have chosen to study the major Wisconsin-age moraines, consisting of the Wabash, Powell-Union City, and Cuba Moraines (Figure 4). The Wabash Moraine lies furthest north, originating in Geauga County, east of Cleveland, Ohio, and extending westward through Celina, Ohio into northern Indiana. To the south of the Wabash Moraine lies the Powell-Union City Moraine, which extends from Mansfield westward through Union City and into northeastern Indiana. The Cuba Moraine lies furthest south of the three moraines used in this study, extending from Newark, westward to Springfield, Ohio, following the southern boundry of the Wisconsin glacial advancement. All three moraines used in this study are approximately two and a half miles wide. The width, aside from some regional variations, remains consistant throughout the length of each moraine.

Figure 3: Glacial Moraine Map of Ohio

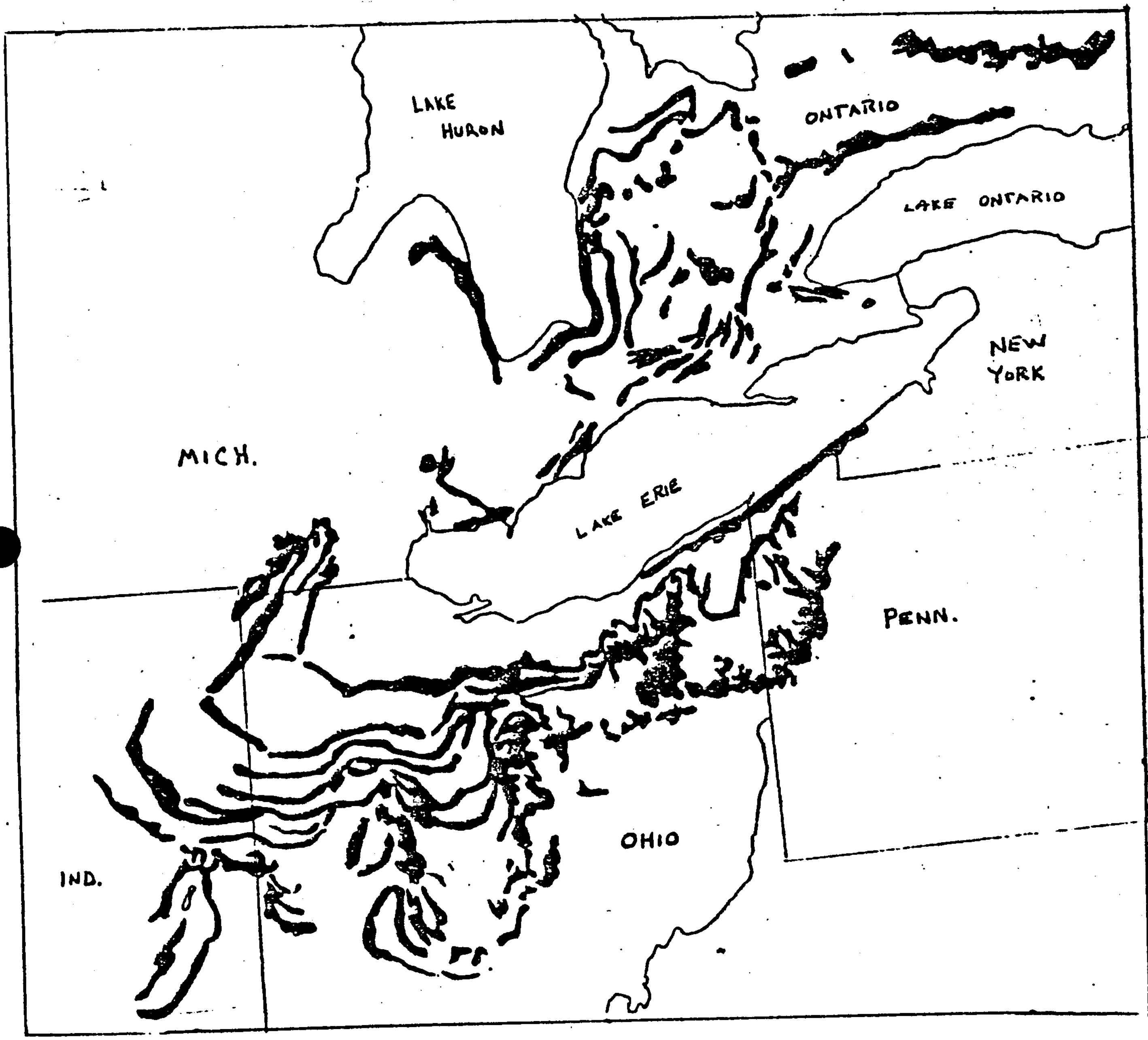
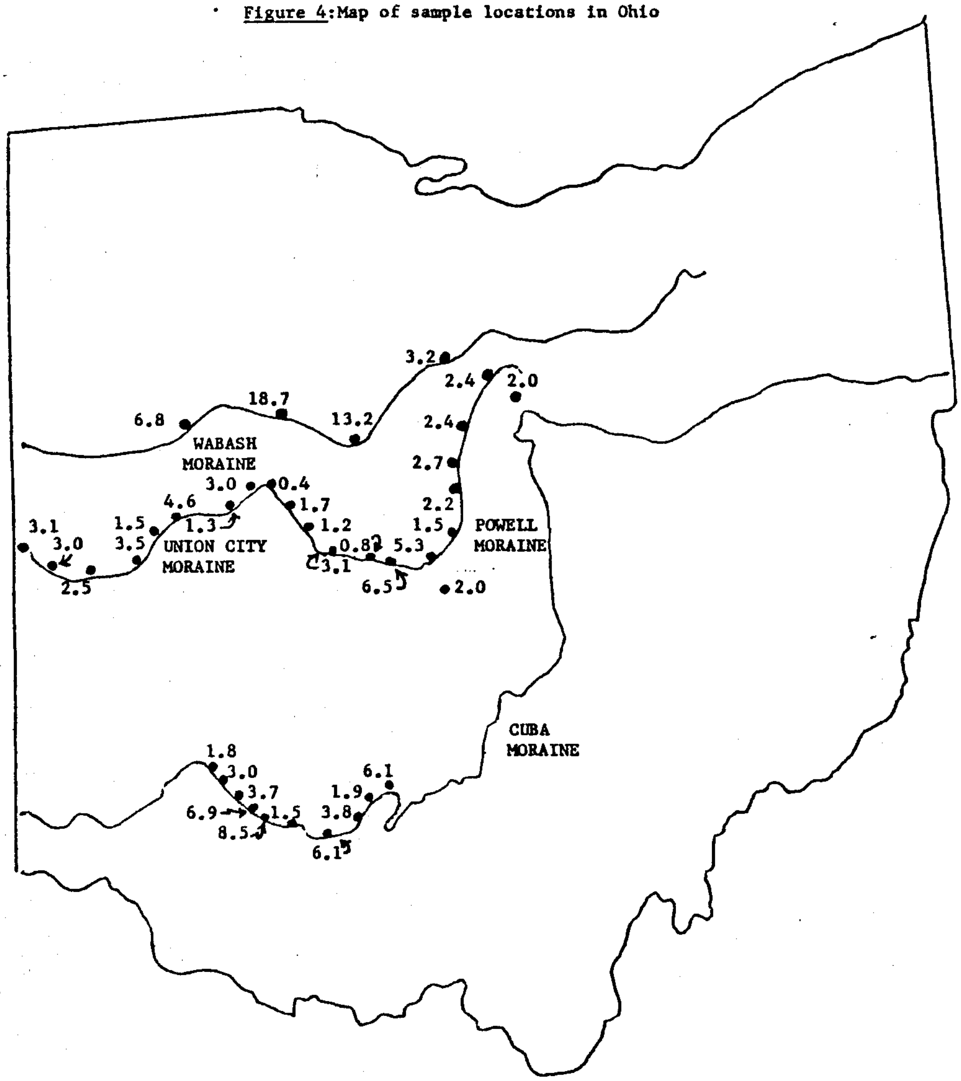


Figure 4:Map of sample locations in Ohio



METHODS OF ANALYSIS

Sample Collection:

The samples were collected by K.S. Taylor and G. Faure for provenance dating of detrital feldspars in the sand-size fractions, and by M.L. Strobel for use in this project. The sample locations (Fig. 4) were chosen at 10-15 mile intervals along the Wabash, Powell-Union City, and Cuba moraines of Ohio. Additional samples were taken from the Union City moraine of Indiana and from the Port Huron, Paris, Galt, Orangeville, and Dummer moraines of Ontario, Canada. Each sample consisted of approximately 10 kilograms collected below the zone of leaching of calcite, wherever possible.

Separation of Clasts:

The clay-size fraction of the till samples was removed by washing the samples. The remaining coarser fractions were dried and then sieved into individual grain-size fractions. All clasts in the +5 mesh fractions were recovered for use in this study; however, clasts more than .5cm in diameter were excluded to avoid distorting lithologic compositions in their favor. The -5+10 mesh fractions were also examined in a small subset of samples for comparison with the +5 fractions.

Abundance by Weight Percent:

The abundance of igneous and metamorphic clasts was expressed in terms of weight percent. This was done by separating the igneous and metamorphic clasts from the sedimentary clasts, then weighing both fractions with a precision of 0.1 grams. The weight of the granitic fraction was then divided by the total weight to determine the abundance of clasts derived from the Canadian Sheild.

In order to test the reliability of the results based on the +5 mesh fractions, the -5+10 mesh fractions of 8 random samples were analyzed by the same method in order to determine the abundance of igneous and metamorphic clasts. This test had two purposes; 1) to determine whether the clast compositions vary with the size fractions. This relates to the statement of Dreimanis and Vangers (1972) that the abundances of minerals in till vary with grain size in a way that depends on distance from the source. 2) to determine whether the clast compositions in the +5 mesh fractions are dominated by large clasts whose weights could distort the abundances of different lithologic varieties.

Abundance by Number Percent:

In order to determine the validity of clast abundances expressed in weight percent, six samples of the +5 mesh fraction were chosen for analysis in terms of percent by number. The samples were sorted into granitic and sedimentary clasts which were then counted. The number of granitic clasts was divided by the total number of clasts in each sample in order to determine the abundance of the igneous and metamorphic clasts in terms of percent by number.

The study of variations accurring between the +5 mesh fraction and the -5+10 mesh fraction (Figure 5) displays a similar pattern in clast abundances. The -5+10 mesh fraction does demonstrate a higher abundance of igneous and metamorphic clasts (see Dreimanis and Vagners, 1972), but remains proportional to the +5 mesh fraction. As long as the +5 mesh fraction samples are consistant as normal abundance representatives of the total sample, this fraction is preferred for this study due to ease of handling and separation.

The clast abundance calculated by weight percent was extremely consistant to the abundance calculated by number percent (Figure 6). Previous studies have involved "pebble counts" as a method to determine abundances (see Anderson, 1955, 1957). In a study involving few samples, this method may be suitable. But over a large region of study, the weight percent method is preferred for two reasons: 1) Practically no variation in the results compared to the number method, 2) much less tedious and time consuming.

Figure 5: +5 Size Fraction vs -5+10 Size Fraction

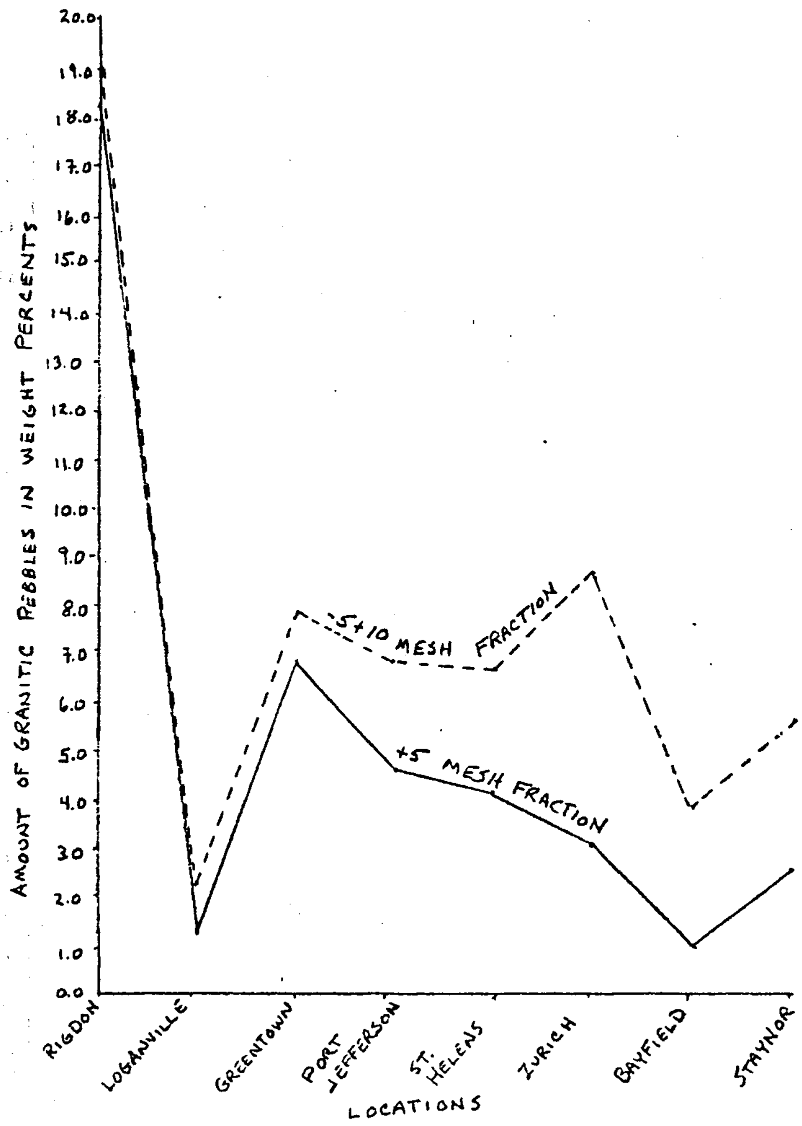
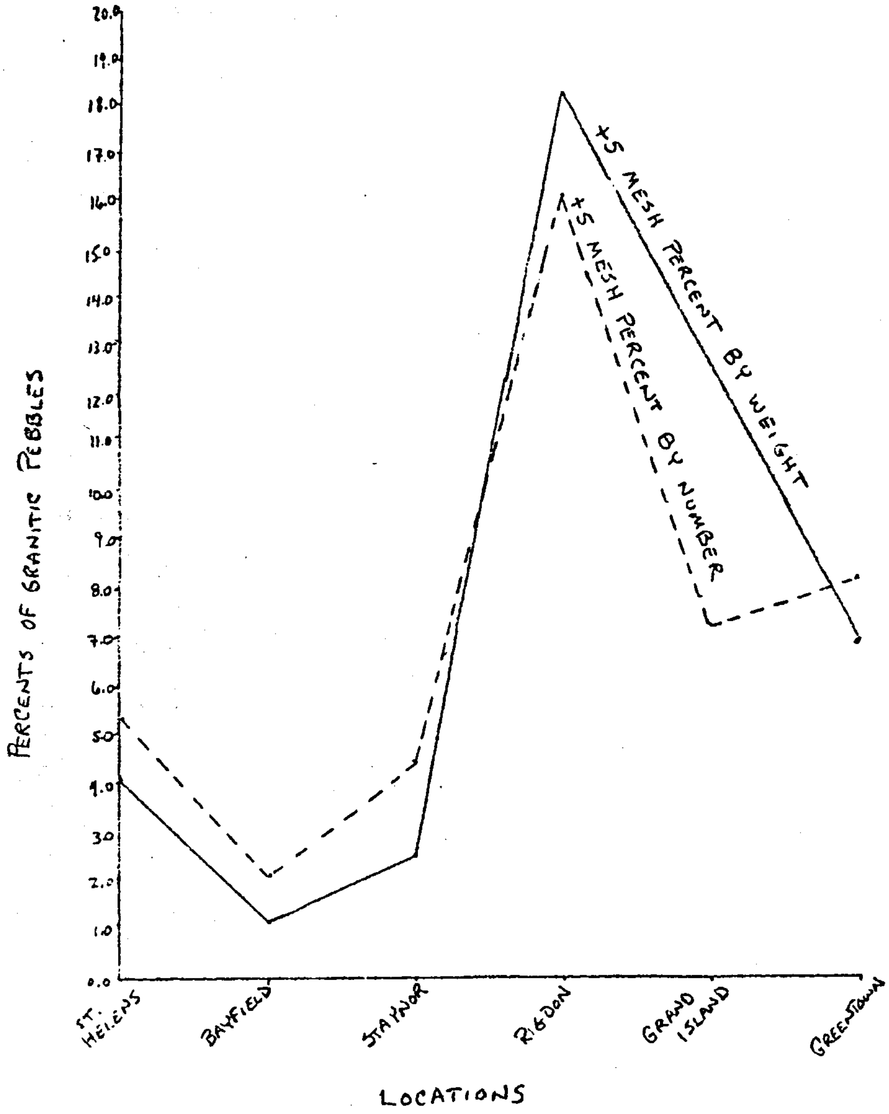


Figure 6: Weight Ratio vs Volume Ratio



RESULTS

Samples from the four Ohio moraines (Table 1 a,c,d,e), were graphed (Figure 7-10) by weight percentages of the igneous and metamorphic clasts in the +5 mesh fractions to determine area of high and low abundances of granitic clasts. All four moraines followed a general pattern of an increase of clast abundance near the apex of each lobe, referred to in this study as the glacial axis, and a decrease of clast abundances near the ends of each lobe, corresponding to the glacial discharge zone. To study this observation, long profiles were taken across the moraines along the glacial discharge zone (A-A' of Fig. 11) and the glacial axis (B-B' of Fig. 11). Results were then plotted as clast abundance vs. location to determine if there are composition variations in the till due to location along the various moraines (Figure 12). The study clearly showed definite variations due to location. The Wabash moraine displayed an increase in clast abundances of 48.5% from the glacial discharge zone to the glacial axis. The Powell-Union City moraine increased an average of 80.9% from the glacial discharge zone to the glacial axis. The Cuba moraine increased an average of 57.9% from the glacial discharge zone to the glacial axis. Overall, the glacial axis has 62.4±18.5% higher abundance of igneous and metamorphic clasts compared to the glacial discharge zone.

Table 1: Abundance of igneous and metamorphic clasts in the +5 mesh fractions of till from Ohio,Indiana and Ontario.

Location	Weight of sample (g)	% igneous/meta. clasts to weight
a) Herrod	228.4	6.79
Kenton	117.9	18.66
Grand Island	62.2	13.20
Bucyrus	138.9	3.24
b) Greentown	168.8	6.81
Rigdon	30.6	18.30
Farmland	12.7	9.45
Union City	143.7	3.13
c) Greenville	148.0	3.04
Gettysburg	281.8	2.48
Piqua	300.6	3.53
Sidney	273.3	1.50
Port Jefferson	495.6	4.62
Logansville	132.7	1.28
Huntsville	382.4	3.01
d) Rushsylvania	188.7	0.37
East Liberty	234.8	1.70
Buck Run	222.7	1.17
Unionville Center	135.0	3.11
New California	229.6	0.83
Powell	258.9	6.49
Galena	107.1	2.71
Sunbury	286.1	1.53
Fulton	295.2	2.20
Mount Gilead	442.4	2.71
Blooming Grove	59.0	2.37
Crestline	304.8	2.36
Mansfield	205.0	1.95
e) Kingman	245.6	1.79
Todd Creek	189.7	2.95
Cowen Lake	369.8	3.68
Martinsville	253.3	6.87
New Vienna	56.2	8.54
Samantha	532.0	1.49
Rainsboro	104.2	6.05
Fruitdale	782.0	3.84
South Salem	358.4	1.93
Lattaville	663.1	6.12

Table 1: Cont.

f) Forest	112.3	5.70
Zurich	473.4	1.13
Bayfield	340.6	1.06
St.Helens	183.3	4.15
Walkerton	371.3	4.01
Berkley	547.0	2.01
Staynor	339.7	2.47
Primrose	8.5	8.24
Eden Mills	510.0	3.22
Paris	804.0	0.77
Langton	79.2	1.51
Uphill	1398.8	1.45
Centre Dummer	1095.7	0.54
Rylston	451.4	1.97
Lakehurst	322.4	97.00
Bobcaygeon	575.2	8.38
Havelock	935.8	6.95
Crookston	258.3	42.10
Marlbank	582.4	3.14

Figure 7:
Wabash Moraine

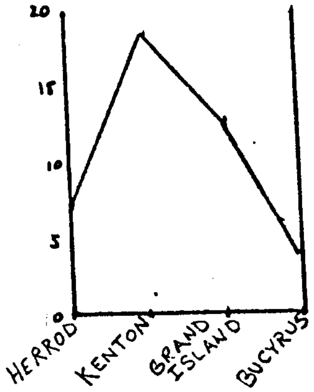


Figure 8:
Union City
Moraine

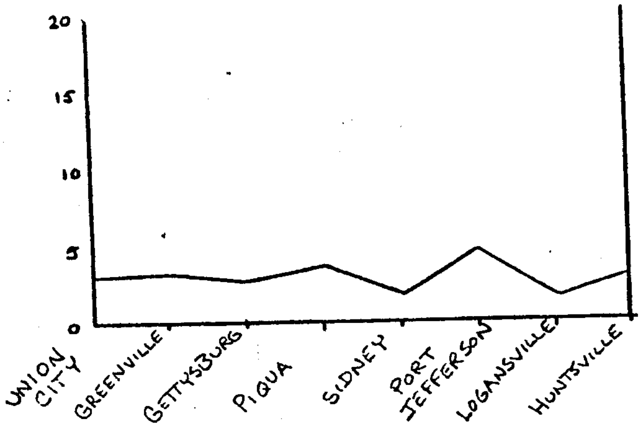


Figure 9:
Powell
Moraine

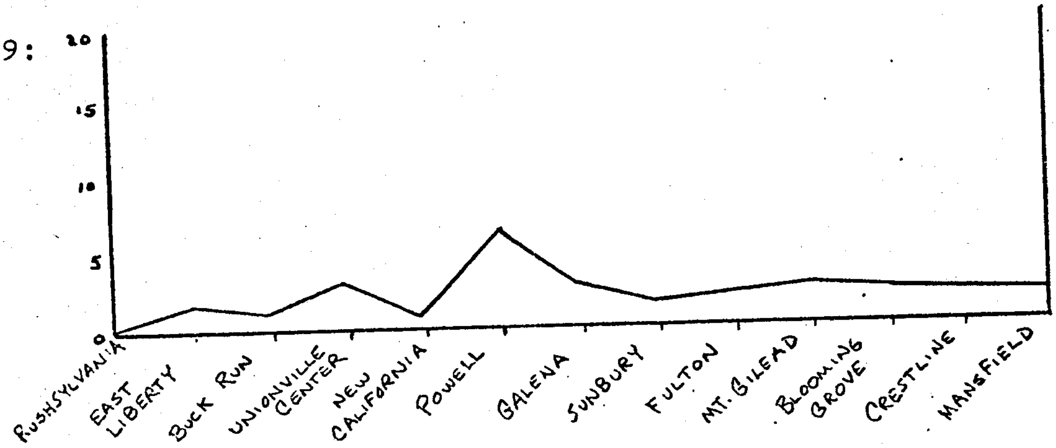


Figure 10:
Cuba Moraine

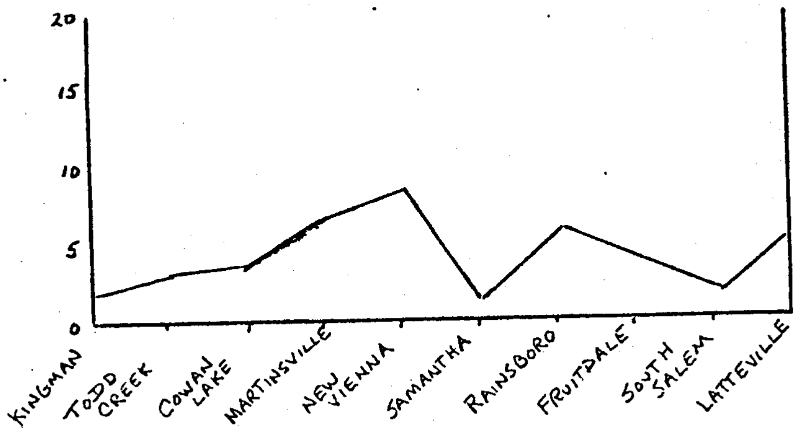


Figure 11: Map of Glacial Axis and Glacial Discharge Zones in Ohio

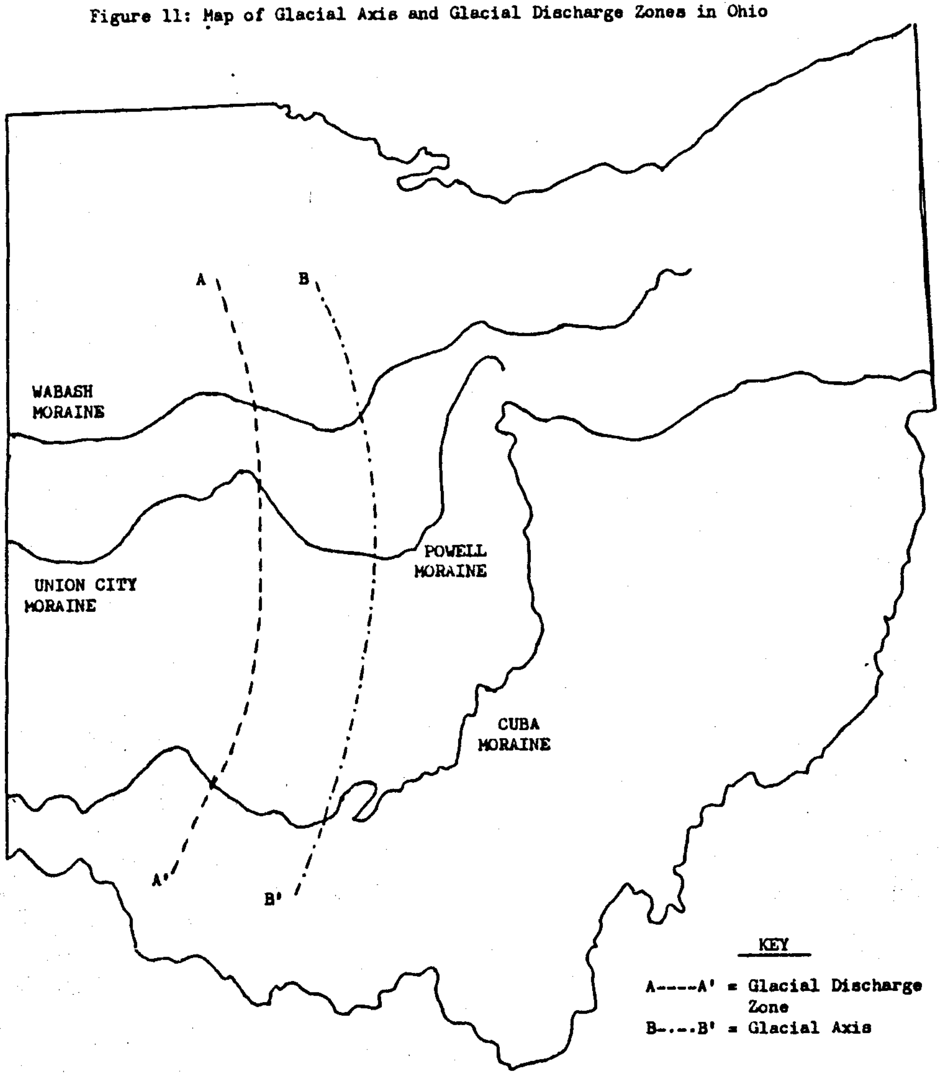
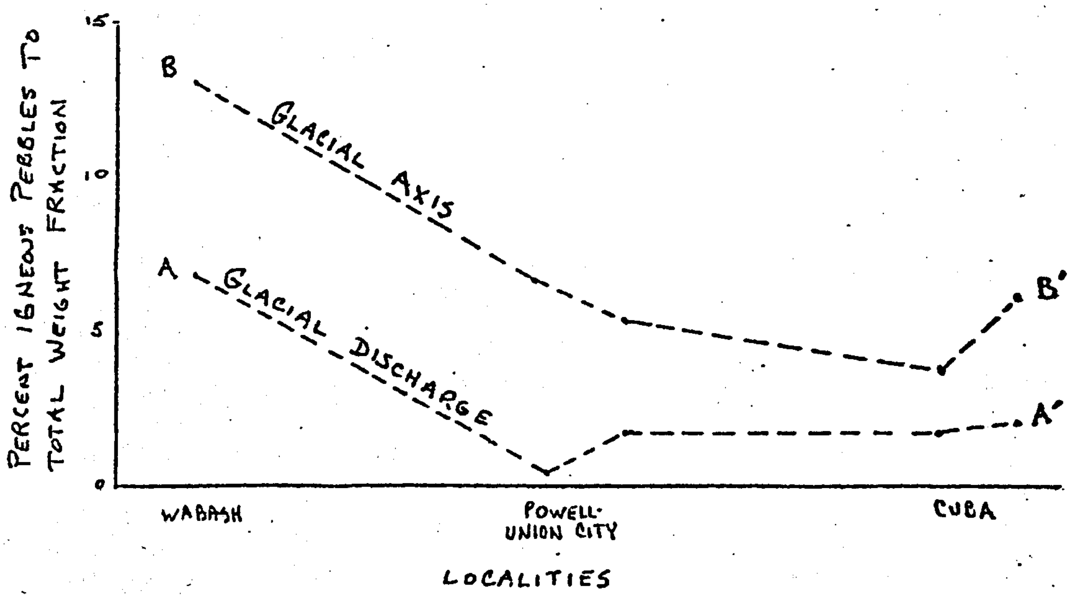


Figure 12: Comparison of Till Composition at Moraine Localities Along the Glacial Discharge Zone vs the Glacial Axis



In studying Figures 7,8,9 and 10 a standard abundance quantity can be determined for the individual moraines. The average abundance of the granitic clasts was determined by observing the patterns in the graphs. In this manner, erratic peaks that are not representative of the general moraine profile can be disregarded the average abundance, unlike the results obtained if a numerical average of percentages at each locality were used. The Wabash moraine was determined to have an average of 10.5% igneous and metamorphic clasts in the +5 mesh fraction. The Union City, Powell, and Cuba Moraines had 3.0%, 2.4%, and 3.5% respectively.

Samples were taken outside Ohio to aid in the interpretation of our results. By widening our scope in a general manner to include parts of Indiana and Ontario, a better overall view of the processss that produced the moraines in this study can be achieved. The four samples from Indiana were taken from the Union City moraine, and have an average abundance of 9.4% igneous and metamorphic clasts (Table 1-b). Samples from Ontario, Canada were taken from Port Huron, Paris, Orangeville, Galt moraines had 8.2, 1.6, and 2.4% igneous and metamorphic clasts respectively. The Dummer moraine, located adjacent to the Canadian Shield, displayed an average abundance of 20.2% igneous and metamorphic clasts. The average of the Dummer moraine was greatly influenced by the Lakehurst sample, which, taken practically on the Canadian Shield, had an abundance of igneous and metamorphic clasts of 97.0% to the total sample weight.

DISCUSSION

Before discussing the results of this study, a short review of the history of each Ohio moraine is necessary. The Cuba moraine is the oldest of the three, estimated to be 18,250±250 years B.P. and represents the furthest advance of the Wisconsin glaciation into Ohio. This advance overran all previous Wisconsin moraines in Clinton, Highland, and Ross counties. The Powell-Union City and Wabash moraines are younger, being 14,780 192 years B.P. and 14,900±450 years B.P., respectively, determined through C^{14} dating (Dreimanis and Goldthwait, 1973).

The variation in age between the Cuba moraine and the Powell-Union City and Wabash moraines should not be a major factor in the abundances of granitic clasts. These recessional moraines are all products of the same glaciation and have the same source provenances.

The variation in till lithologies caused by the advancement of the Cuba moraine over previously deposited materials could be of major importance. As previously stated in the Introduction, the reworking of older deposits can create a new till of different composition. This addition of previously deposited glacial till to the sediment in transport by the ice sheet may cause an increase in the abundance of igneous and metamorphic clasts being transported by the ice. If true, this concept could have an adverse effect on the simple relationship between the abundances of granitic clasts and transport distance proposed by the model. Since the Powell-Union City and Wabash moraines represent recessional moraines and show no evidence of resurgance over previously deposited Wisconsin moraines, this addition effect is not considered to be a major factor in the abundance of granitic clasts.

The Wabash moraine (Figure 7) has a very large abundance, approximately 10.5 percent, of igneous and metamorphic clasts in comparison to the other lithologies. Assuming an inverse linear relationship between distance, the rate of decrease is 1.54×10^{-1} percent per kilometer of advance. In comparison, the Powell-Union City moraines (Figures 7 and 8) have an igneous and metamorphic clast abundance of approximately 2.7 percent and show a decrease rate of 1.52×10^{-1} percent per kilometer. With a total variation of only 1.32 percent between the two rates, the simple distance/abundance model appears to be quite valid. This does not hold true, though, when examining the samples collected from the Port Huron, Galt, Orangeville, and Paris moraines of Ontario, Canada. In these localities, the decrease rate is 5.12 ± 0.90 percent per kilometer. The difference between this rate and that calculated for the Wabash and Powell-Union City moraines is quite significant in the understanding of glacial mechanics. If the distance/abundance model is valid, as the results of the Wabash and Powell-Union City moraines appear to suggest, then there must be a major change in the rate of change of abundance versus distance as the ice flowed away from the granitic provinances onto the Paleozoic sedimentary formations. One possible explanation to the significant decrease in the abundances of granitic clasts in Ontario is that as the ice advanced from the hard granitic bedrock of the Grenville and Superior Provinces onto the softer Paleozoic limestones and shales, there occured a massive increase in the number of clasts due to the lower erosional resistance of the bedrock. As a result, the number of igneous and metamorphic clasts remained constant while their percent abundance in the sediment decreased by the introduction of the soft sedimentary clasts. As transportation continued, the Paleozoic sedimentary clasts proved to be less resistant to mechanical weathering by ice which caused the abundance of granitic clasts to become constant or even to rise slightly with increasing distance as seen in the Wabash and Powell-Union City moraines.

In the Ontario samples there is a large deviation in the abundance of granitic clasts between the various moraines of the Ontario lobe. Two major moraines, the Port Huron and the Paris, are prime examples of this variation. The Port Huron moraine was deposited a distance of 250±25 kilometers from the precambian shield, and contains up to 5.2 percent igneous and metamorphic clasts. The Paris moraine was deposited 100 25 kilometers from the edge of the Shield and contains up to 2.5 percent igneous and metamorphic clasts. The Port Huron moraine has a decrease rate of 3.77×10^{-1} percent per kilometer, while the Paris moraine decreases at a rate of 9.75×10^{-1} percent per kilometer. Once again, this appears to contradict the distance/abundance model. May and Dreimanis (1973) performed studies on tills of southern Ontario in the -0.037mm size fraction using atomic absorption spectrophotometry, and obtained results that suggested that in the northwestern part of the Ontario Lobe area, the glacier must have overridden and incorporated pre-existing sediment derived from a northern source. The mixing of the previously deposited till with the sediment carried by the glacier explains the larger abundance of igneous and metamorphic clasts in the Port Huron till. This relationship was previously observed in the samples of the Cuba moraine in comparison to the Wabash and Powell-Union City moraines, thus supporting this theory on abundance increases due to reintroduction of older glacial sediments.

Individual moraine lobes, as described in the Results section, display an increase in their abundances of igneous and metamorphic clasts near the apex of the lobes, referred to in the text as the glacial axis, in comparison to the terminations of the lobes, referred to as the glacial discharge zone(Figure 5). An examination of basic glacier mechanics offers some explanation. Glacial abundances caused by increased accumulation and decreased atmospheric temperatures produce massive erosional changes to the landscape. As the glacier erodes the underlying bedrock through extreme weight and friction, the fractured sediment is transported in the ice and later deposited through the process of ablation. The surface of the ice mass is subjected to temperature variations of the atmosphere that prove to be less stable than the internal temperatures of the glacier. Melting, and therefore deposition, occurs at the exposed perimeter of the glacier at higher rates than the internal melting. For this reason, tills in the lateral moraines better represent the regional lithology. Terminal moraines, on the other hand, contain till that is representative of sediments transported for great distances. This concept is applicable to the study of abundance variations occuring in the Ohio glacial lobes. The glacial discharge zone is comparable to lateral moraines, likewise the glacial axis is contained in the terminal moraine. The glacial axis, due to a greater stability, is a better representative of the distance/abundance model.

SUMMARY

The concept of an abundance proportional to distance model is valid, accounting for deviations produced through external processes. The Wabash and Powell-Union City moraines of Ohio produced a generalized decrease rate of $1.53 \pm 0.01 \times 10^{-1}$ percent per kilometer of the igneous and metamorphic clasts to the total till composition. Other moraines involved in this study deviated from this experimental value due to incorporation of previously deposited till, dramatic contrasts in the underlying bedrock, and physical position in the body of the ice sheet.

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